15848

Development, optimization, and design for robustness of a novel FMVSS 201U energy absorber

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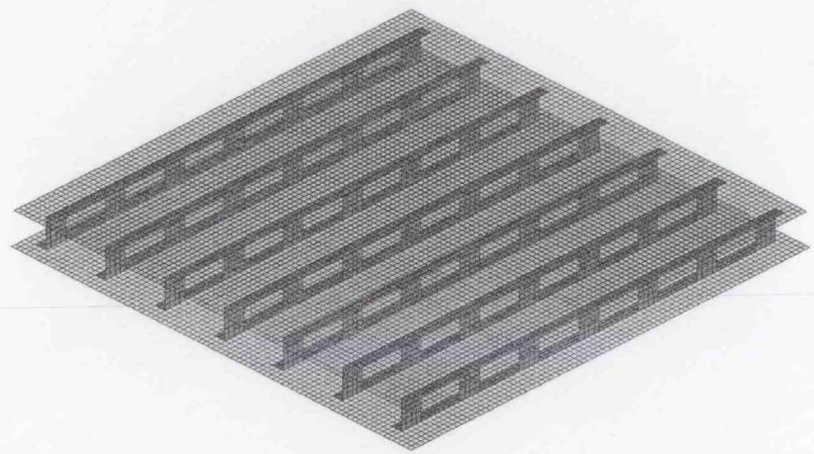
Introduction

- Significant opportunity to improve vehicle occupant safety
- Reduce impact severity between occupant heads and vehicle interiors
- Rigid body panels
- Used plastic deformation of mild steel fins and cover sheet to absorb impact energy

Absorber construction

- 0.5 inch wide mild steel fins
- Connected with a mild steel web
- Sandwiched between mild steel surface panel and rigid armor

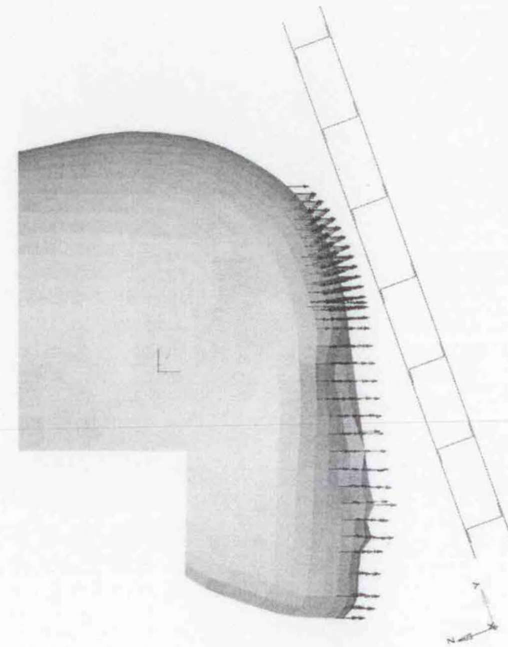


LS-DYNA absorber model

- Connected fin / web assembly to cover sheet using spot welds
- Used SPC to anchor fins at interface between absorber and rigid panel
- Type 13 contacts between the various assembly components
- Nominal 3 mm mesh
- Steel was modeled using MAT24

Impact test simulation

- FMVSS 201U
- Component level, 10 inch X 10 inch surface
- FTSS v. 3.6 free motion headform
- 15 mph initial velocity
- 20° angle between velocity and surface



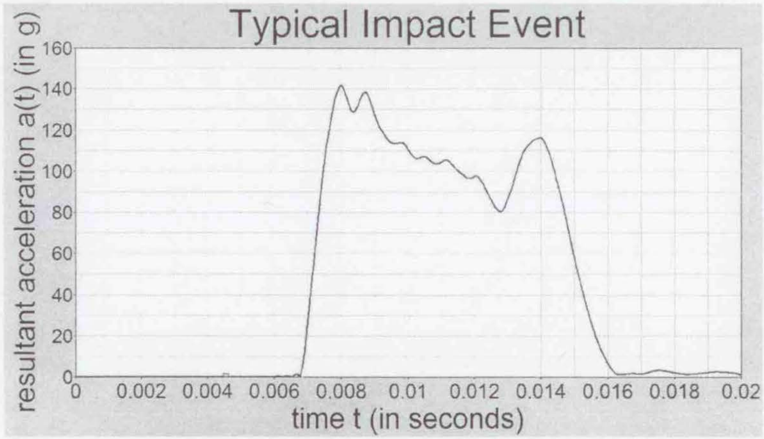
Optimization problem

- Minimize crush space subject to the constraint that HIC(d) < 700
- Independent variables:
  - crush space
  - spacing between fins
  - shell thickness of fin, web, and cover sheet

Head Injury Criterion (HIC)

$$HIC = \max_{t_1, t_2} \left\{ \left[\frac{\int_{t_1}^{t_2} a(\tau) d\tau}{(t_2 - t_1)} \right]^{2.5} (t_2 - t_1) \right\}$$

$$HIC(d) = 0.75446\,(HIC) + 166.4$$



- HIC is used to estimate the severity of head impact events
- HIC(d) is a correlation between free motion headform HIC and HIC for a full 50^{th} percentile dummy
- In the expression for HIC, a(t) is defined as the resultant acceleration as a function of time, t_1 and t_2 are any two points in time during the impact separated by not more than 36 milliseconds.
- Lower HIC is better, FMVSS 201U requires that HIC(d) be less than 1000

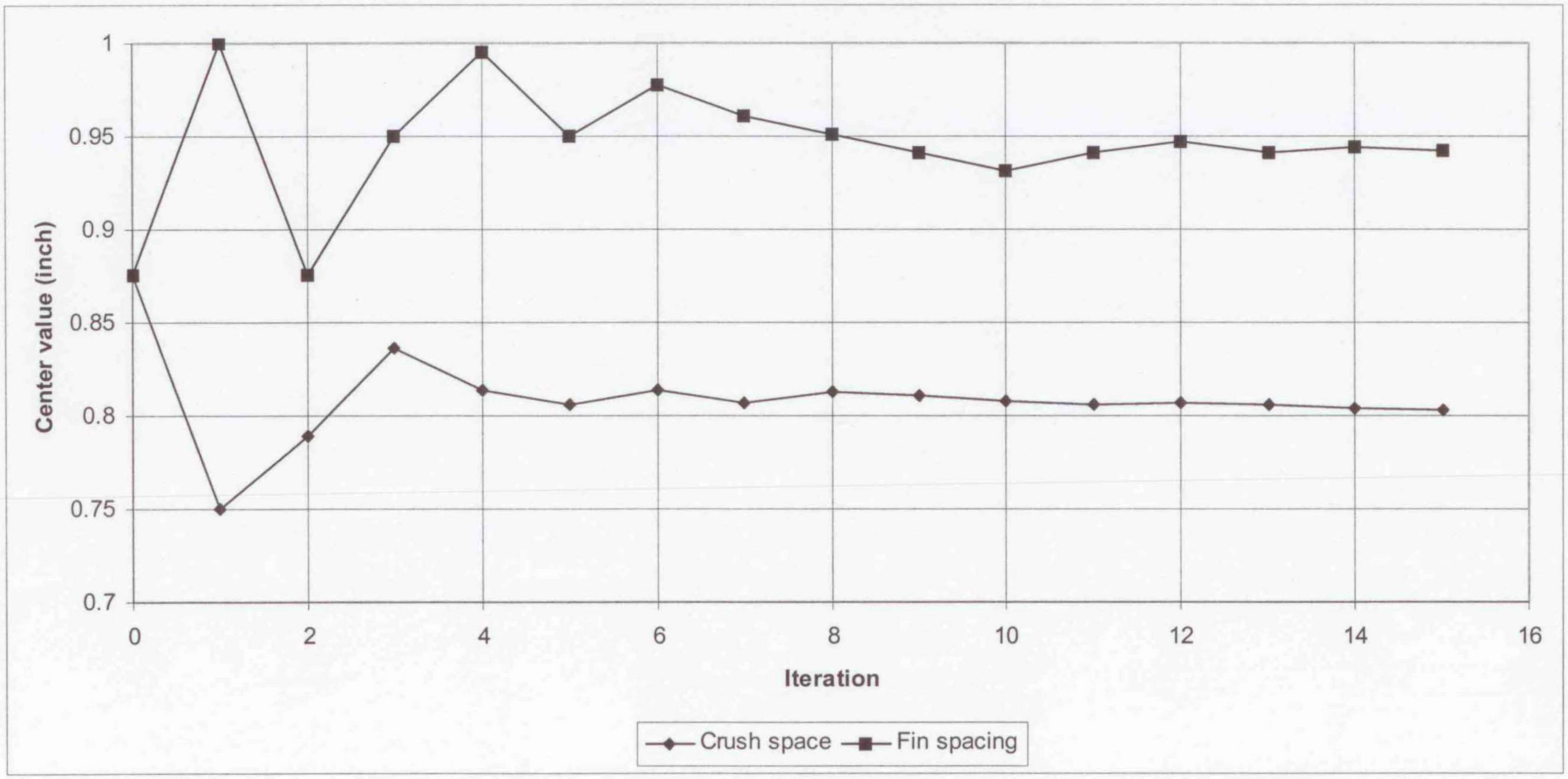
Optimization technique

- Closely followed Stander and Craig (LS-OPT) successive response surface method
- Iterative sequence of linear least squares response surfaces
- Chose D-Optimal subsets of 3^3 full factorial basis designs
- D-Optimal subsets contained seven combinations of the three design factors
- 15 iterations of 7 runs each; 105 simulations overall

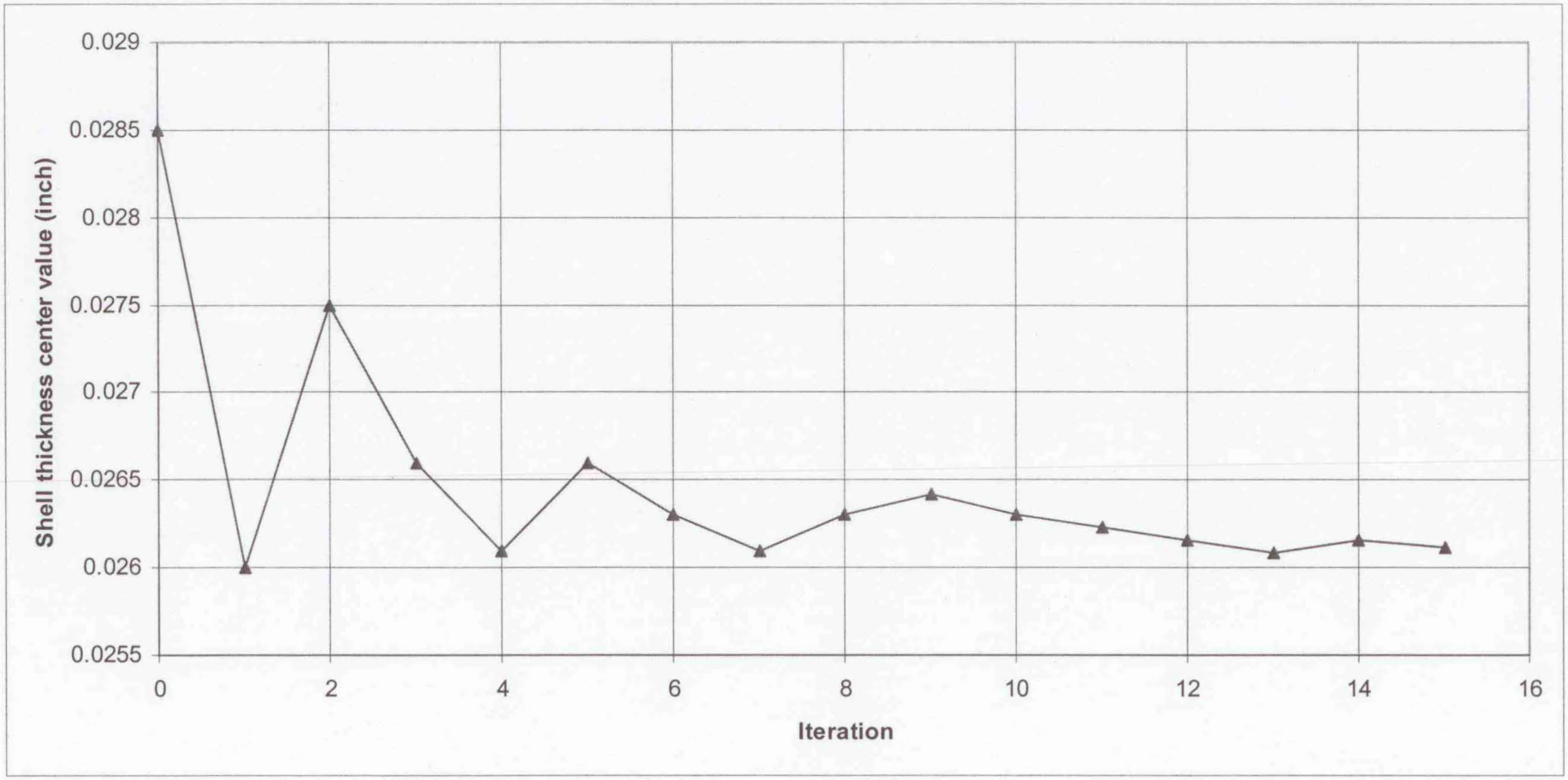
Convergence to optimum values

	Initial	Optimum
Crush space (inch)	0.875	0.8044
Fin spacing (inch)	0.875	0.9446
Fin / web / cover shell thickness (inch)	0.0285	0.02616
HIC(d)	737	699

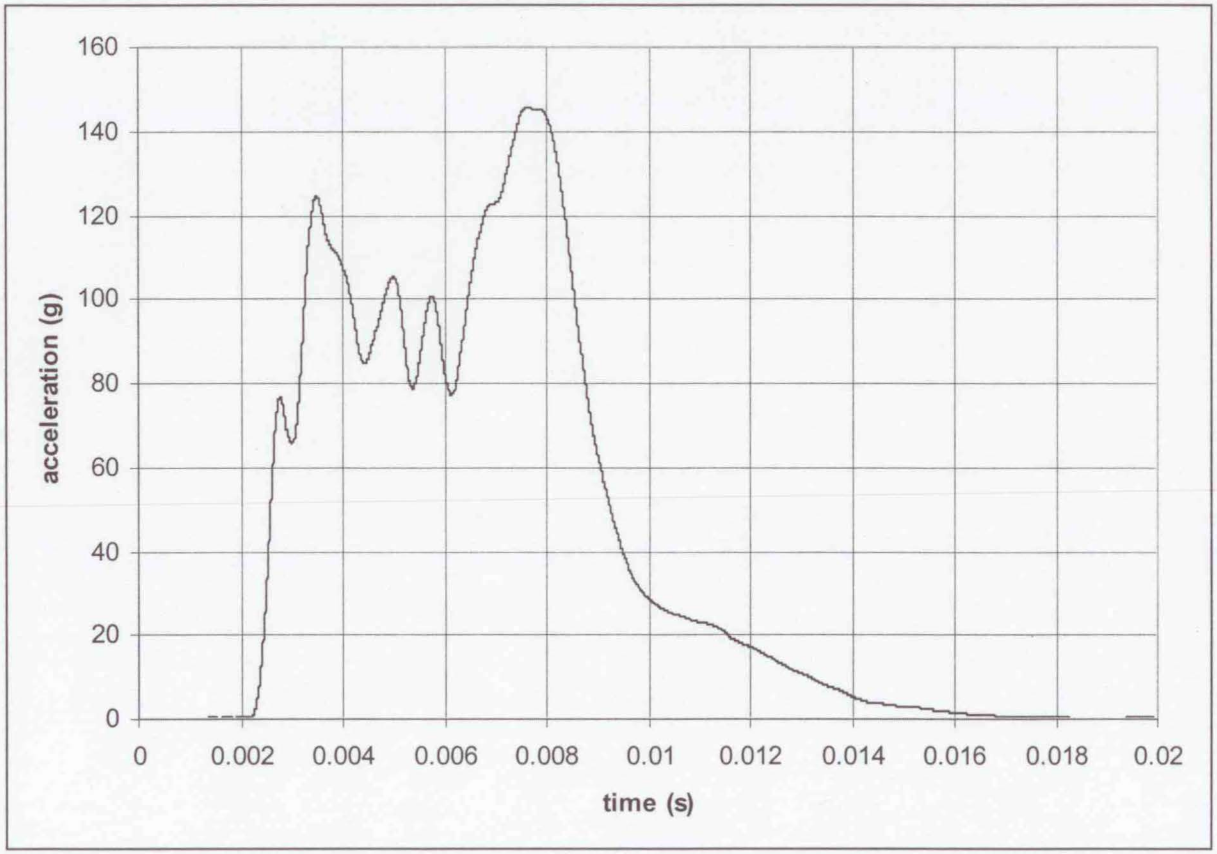
Convergence – crush space and spacing



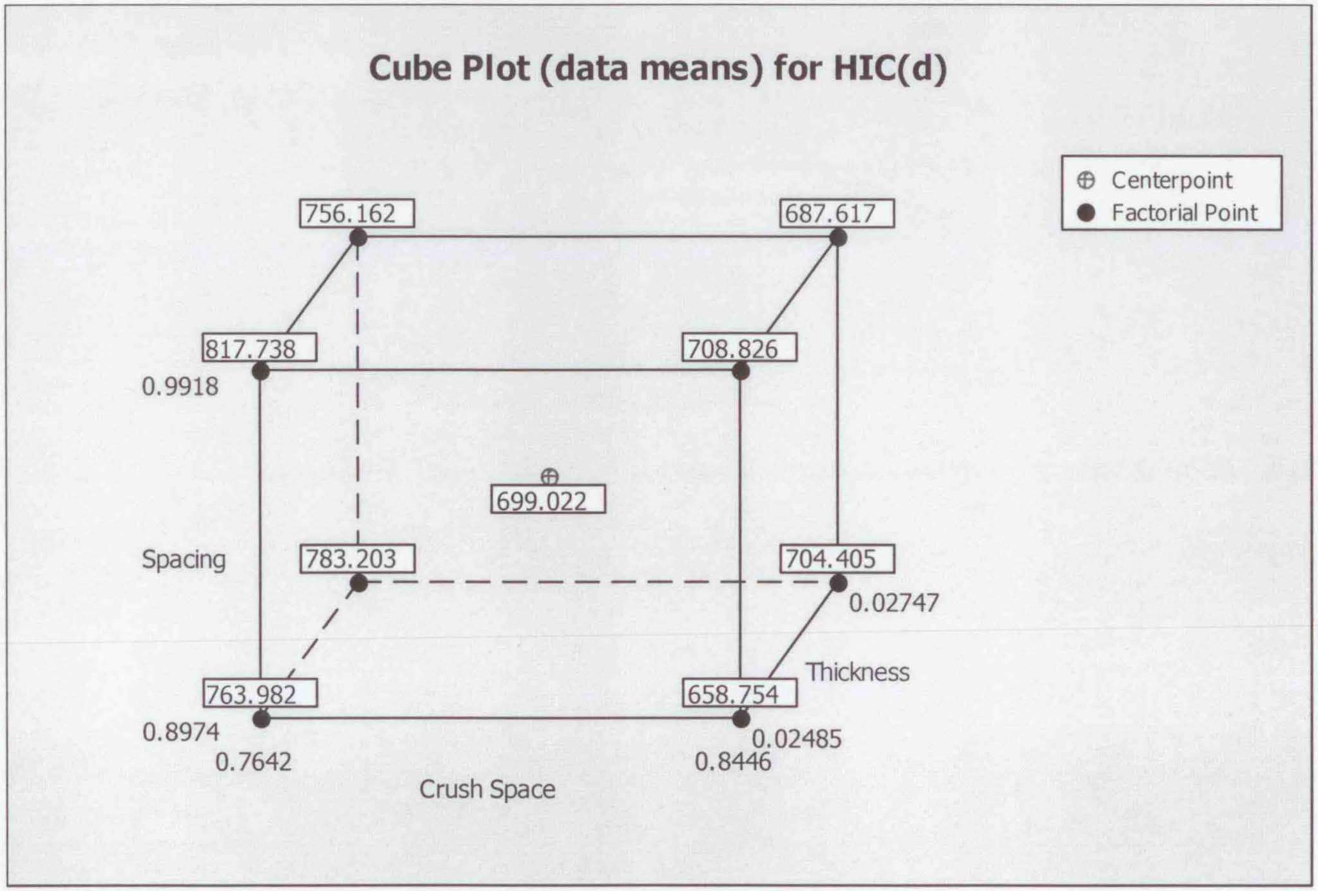
Convergence – shell thickness



Acceleration – time history for optimum design

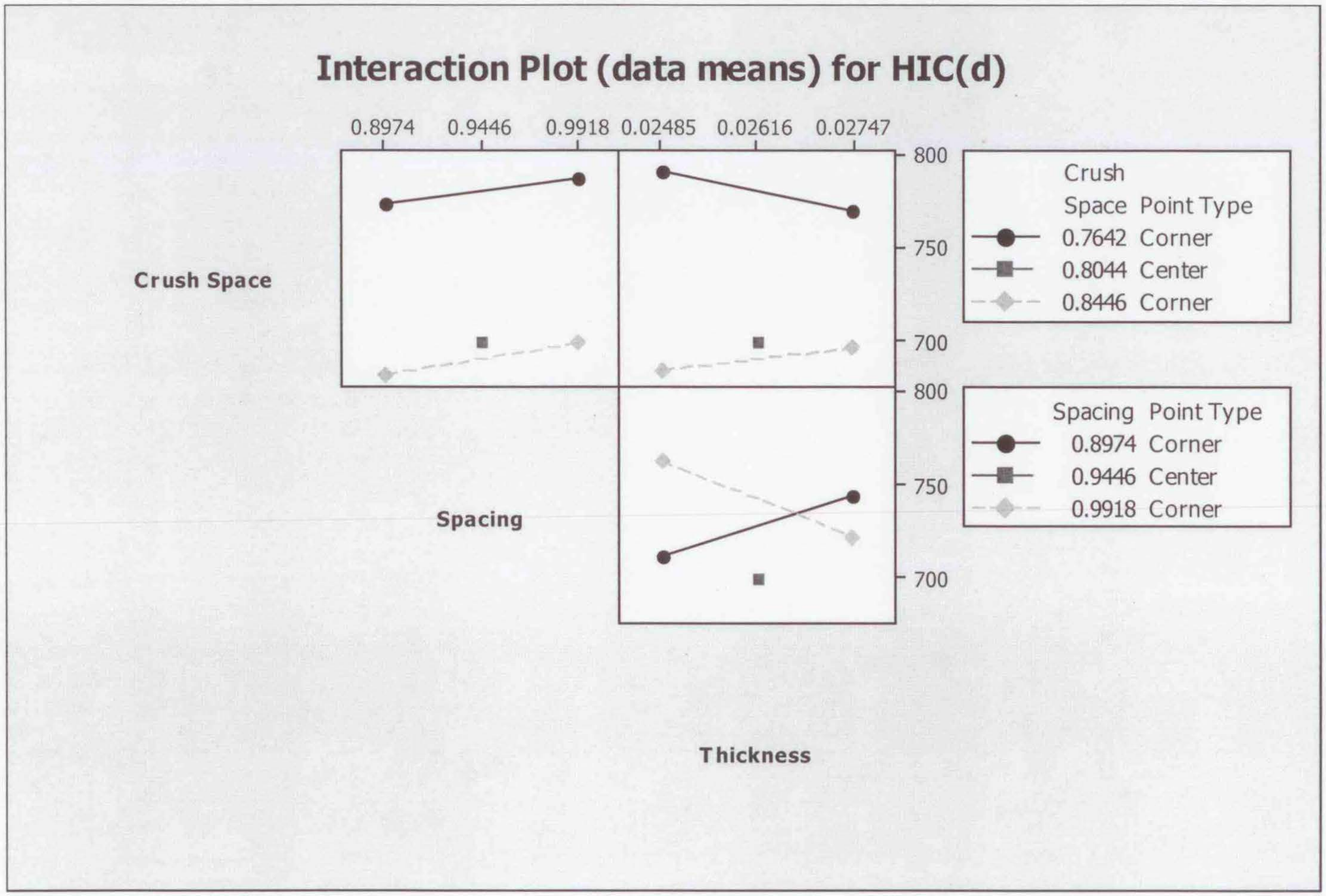


Variability / robustness

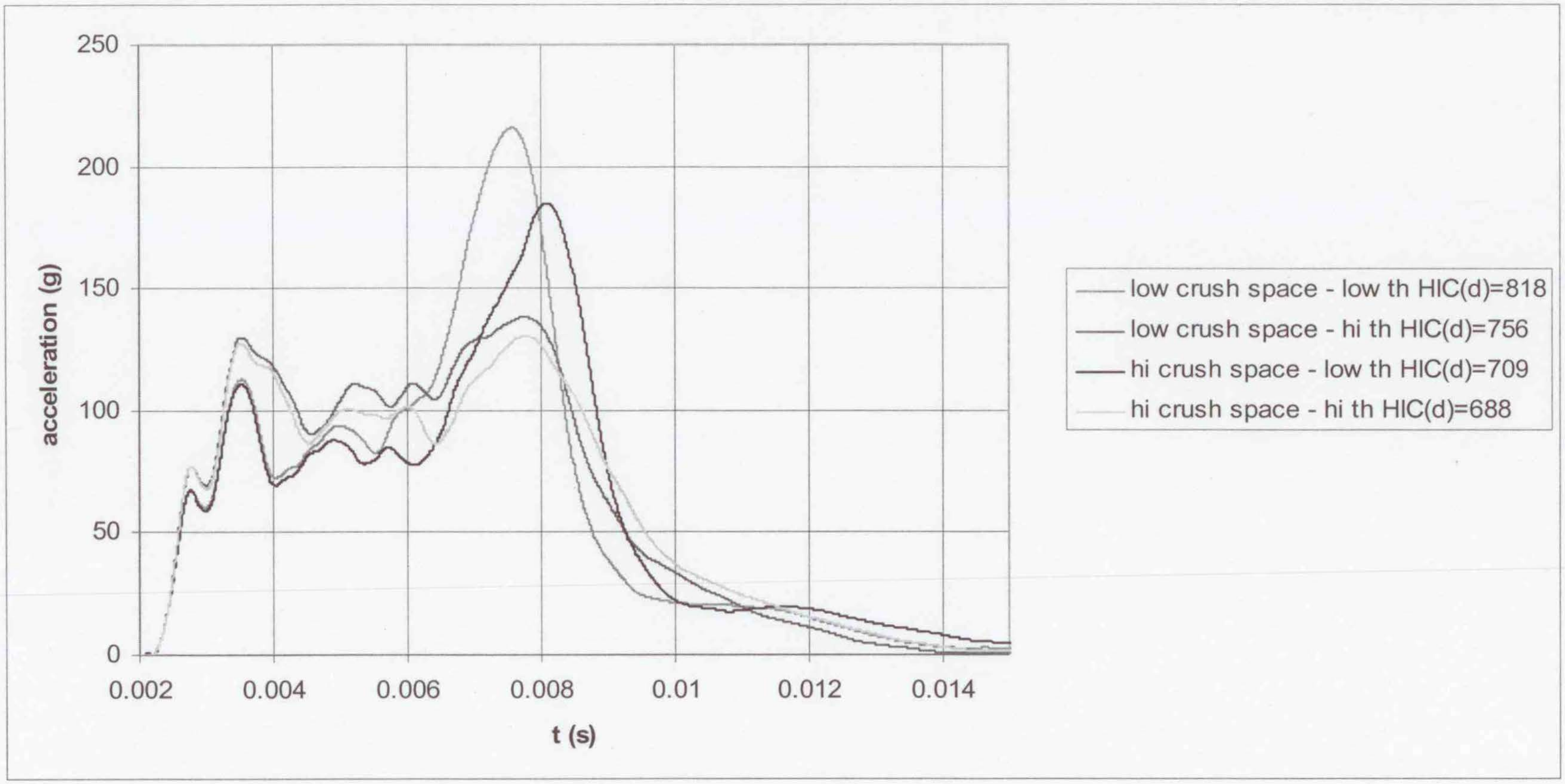


- 2^3 full factorial about optimum
- Optimum design settings ± 5%

Initial design interaction

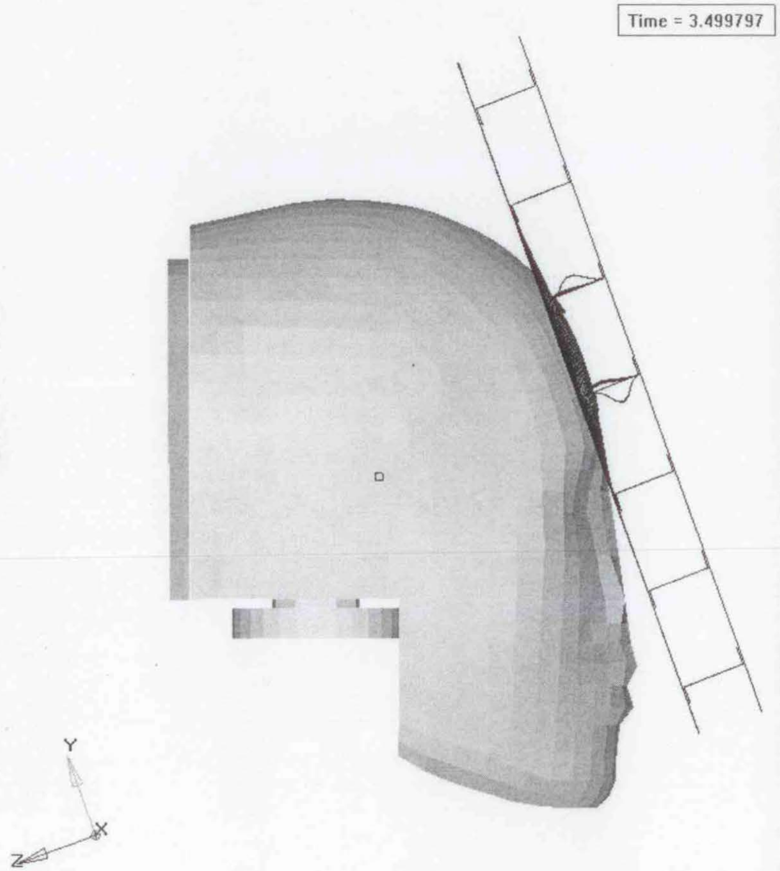


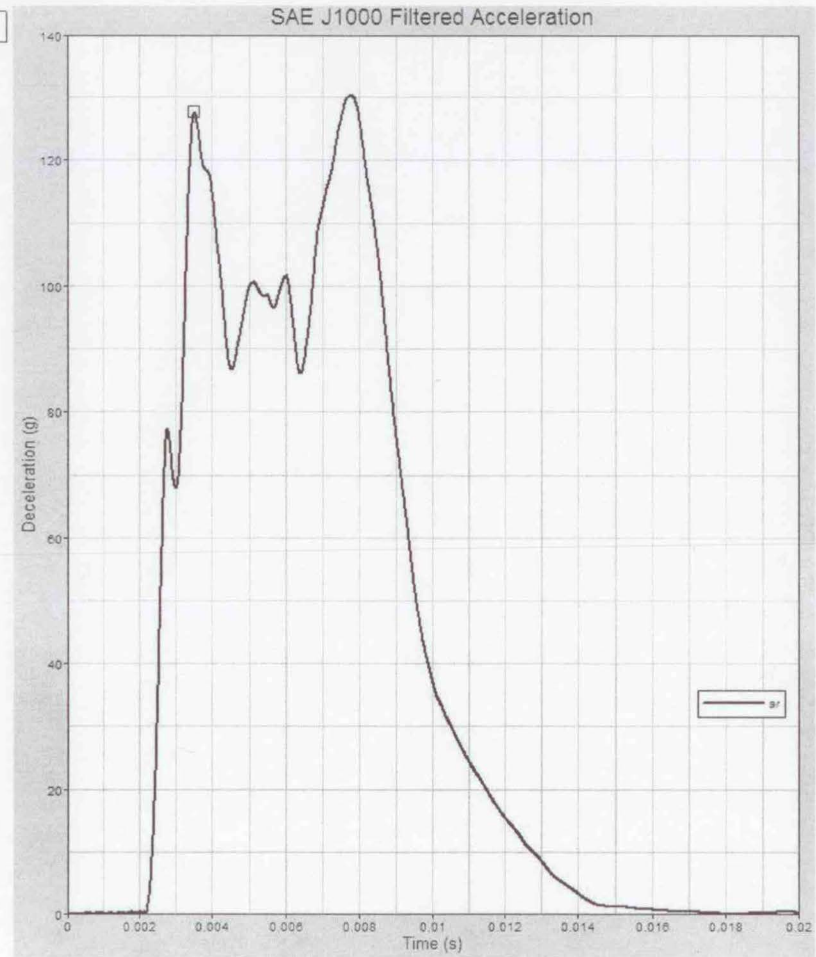
Crush space – thickness interaction



- Lower shell thickness increases propensity toward "bottoming out"
- Lower crush space tends to increase mean deceleration

HIC(d) = 688, first peak





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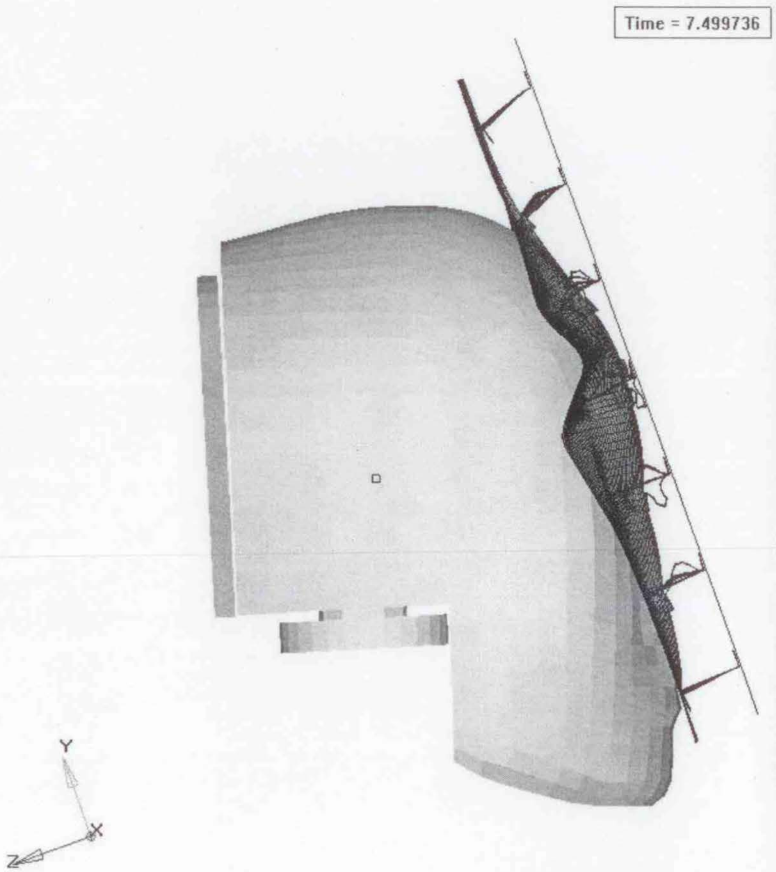
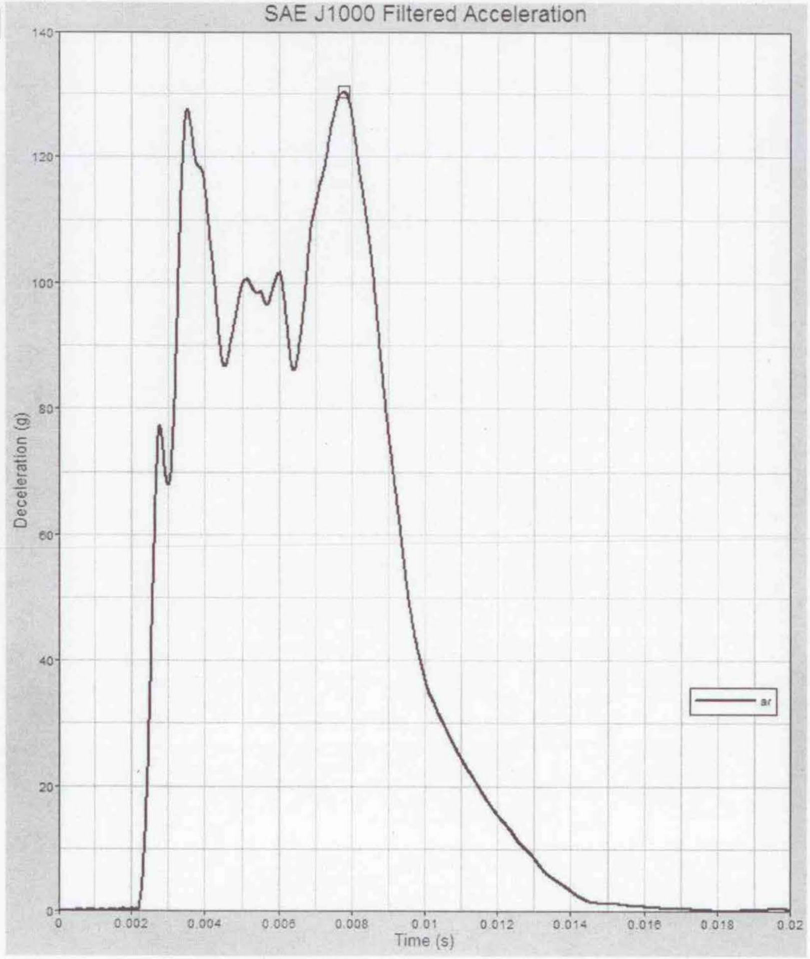
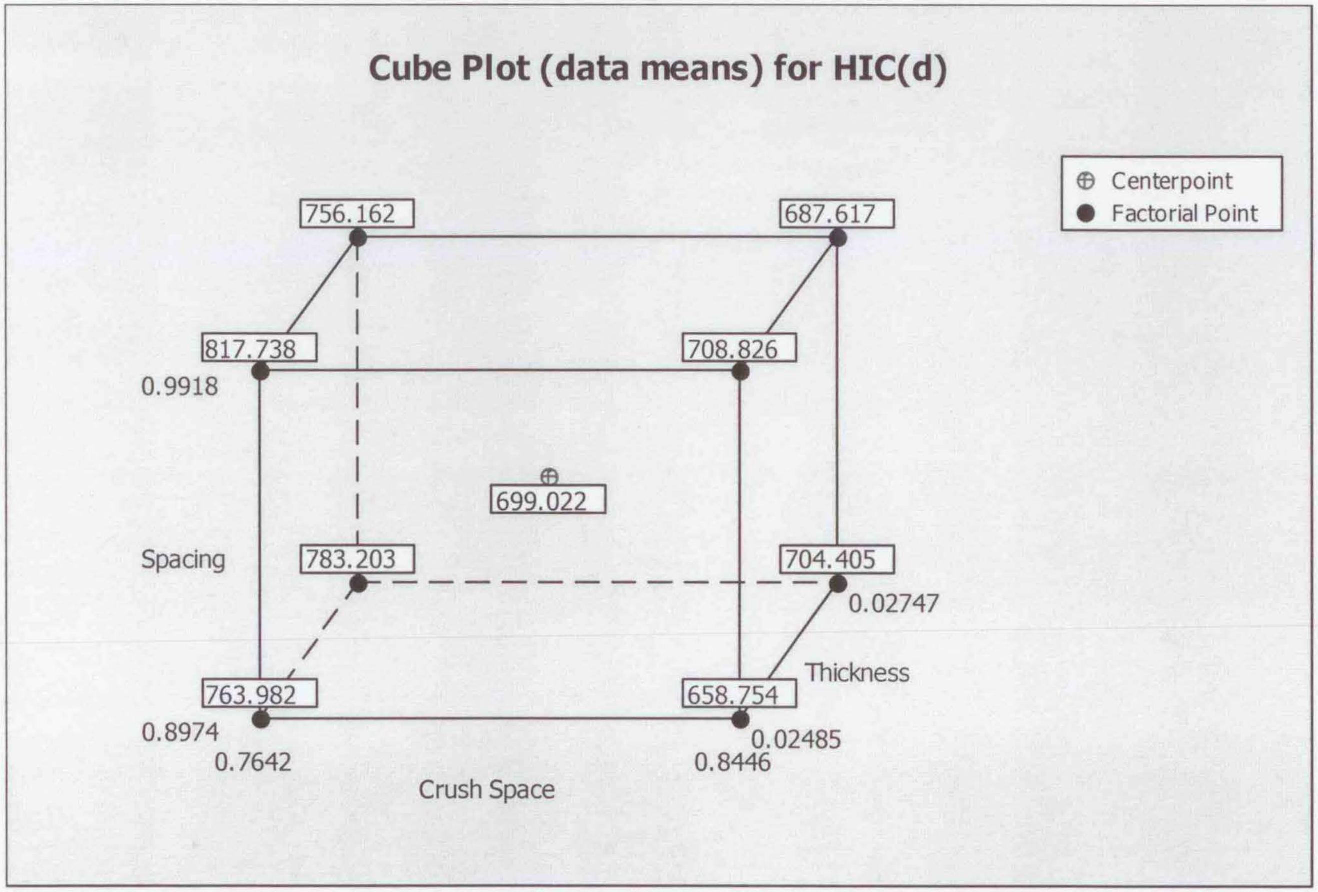


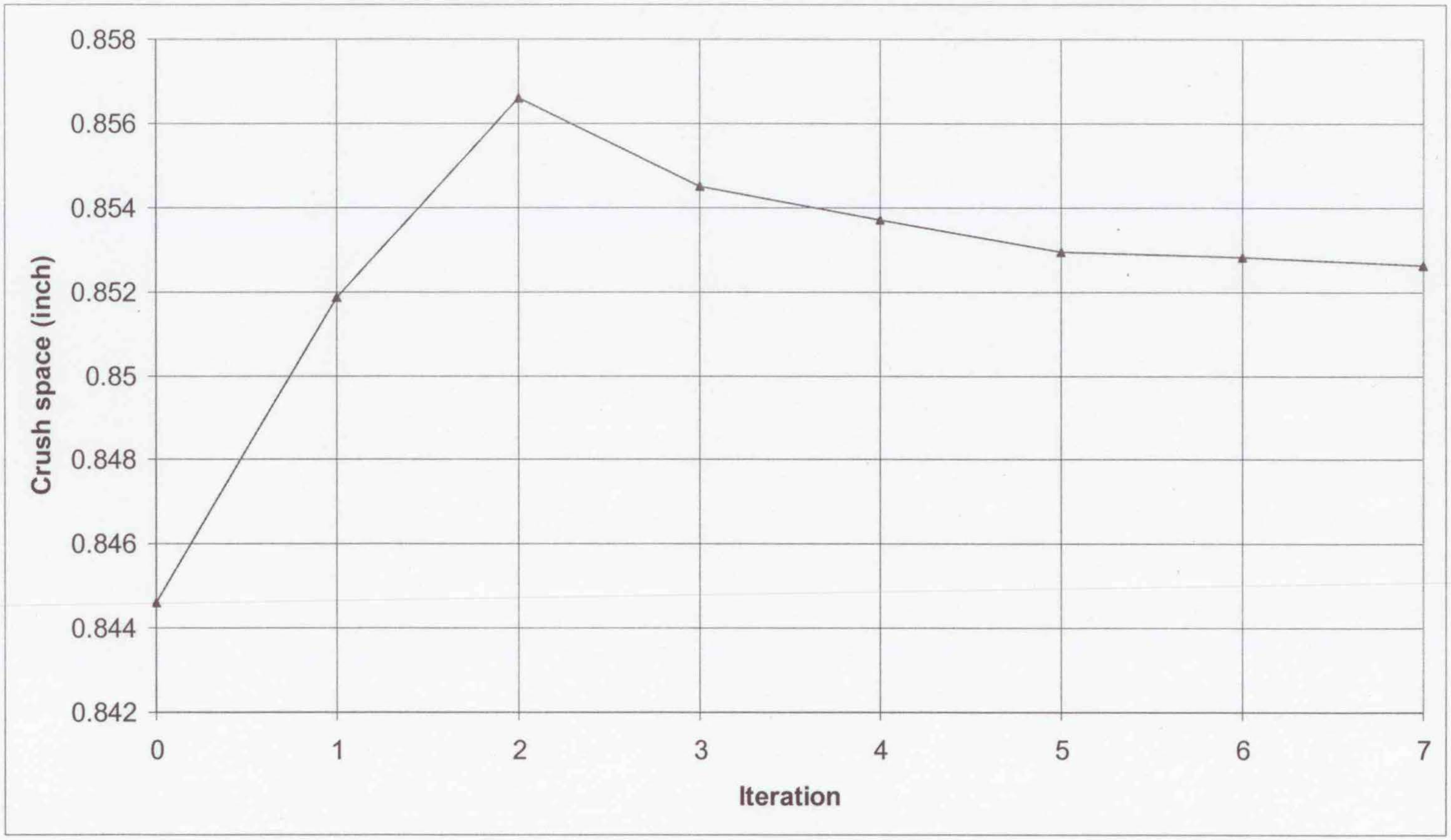


Improve design



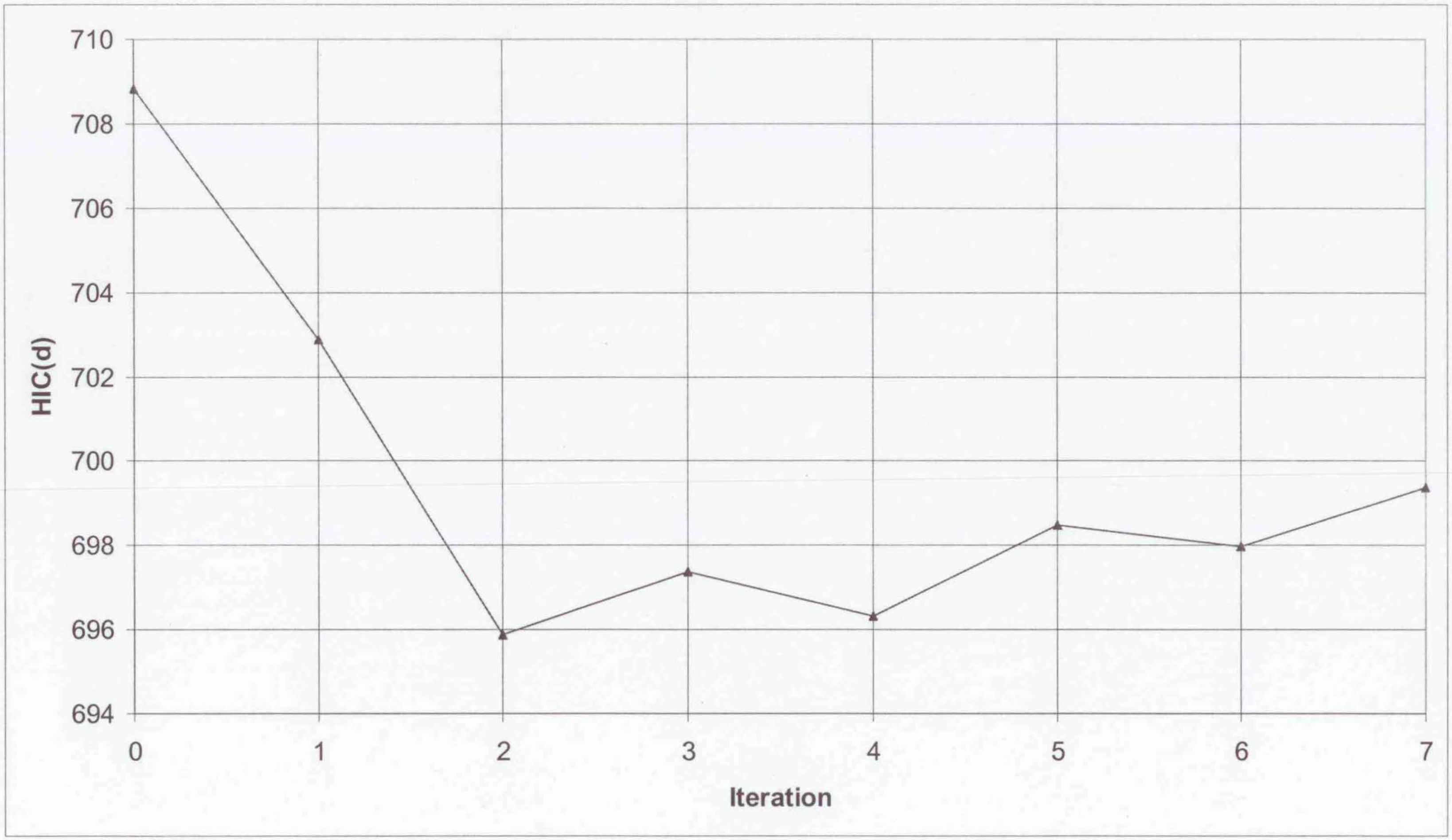
- ~5% increase in crush space should enable HIC(d) < 700
- Use 0.84 crush space face as starting point

Design improvement

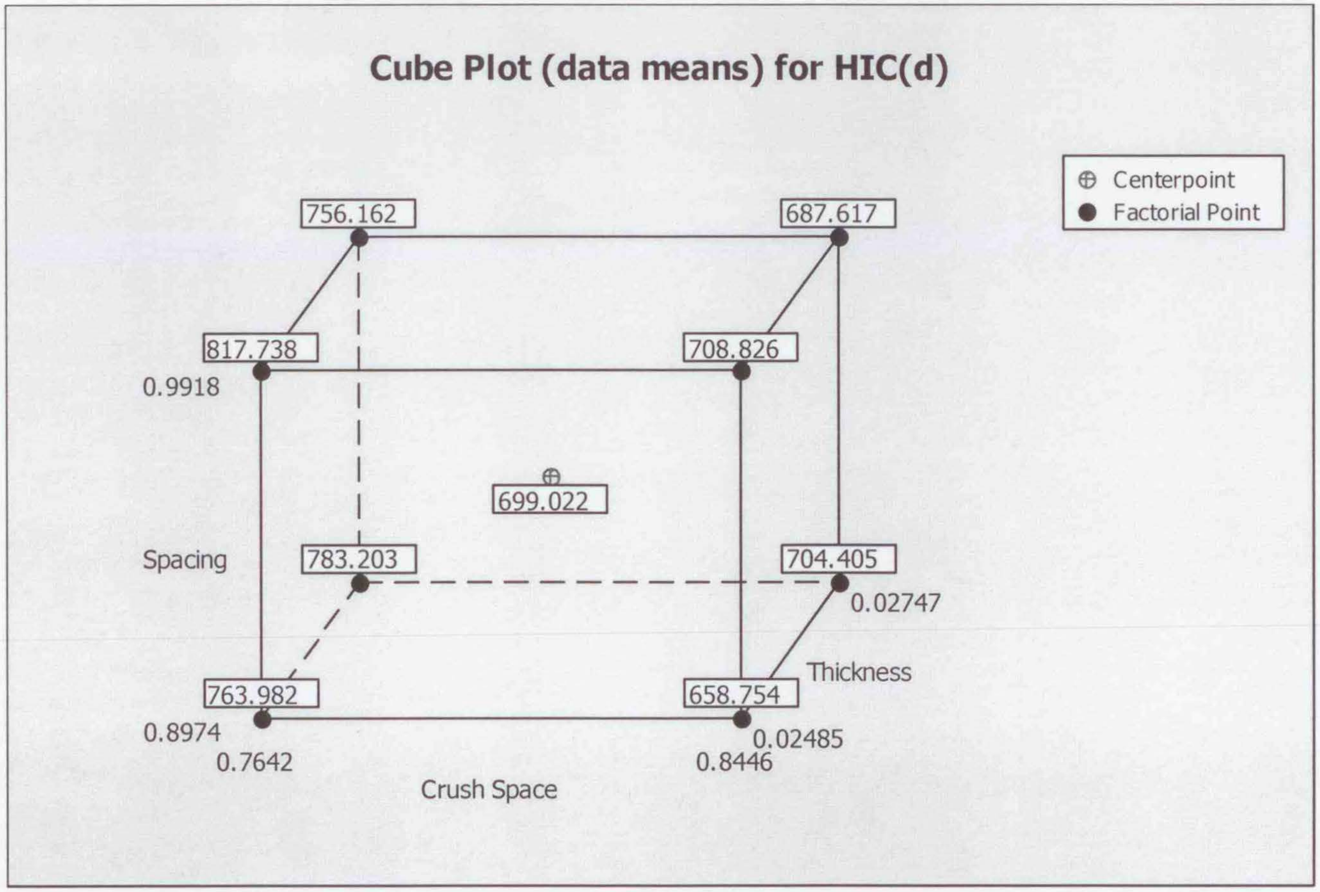


- Used interpolation process keeping spacing and thickness fixed
- Found new crush space to ensure HIC(d) < 700 for nominal parameter settings ± 5%

Design improvement



Improve design



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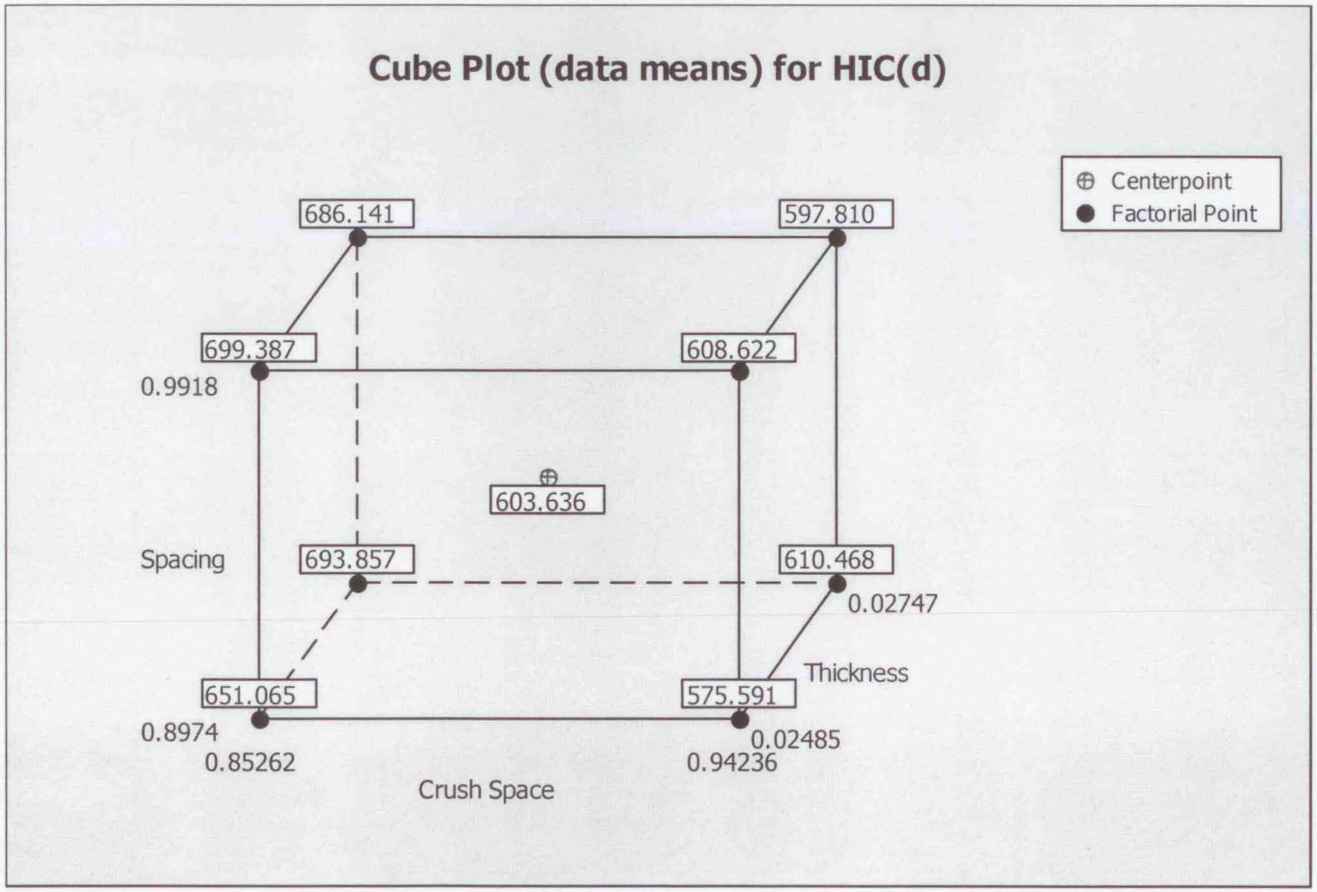
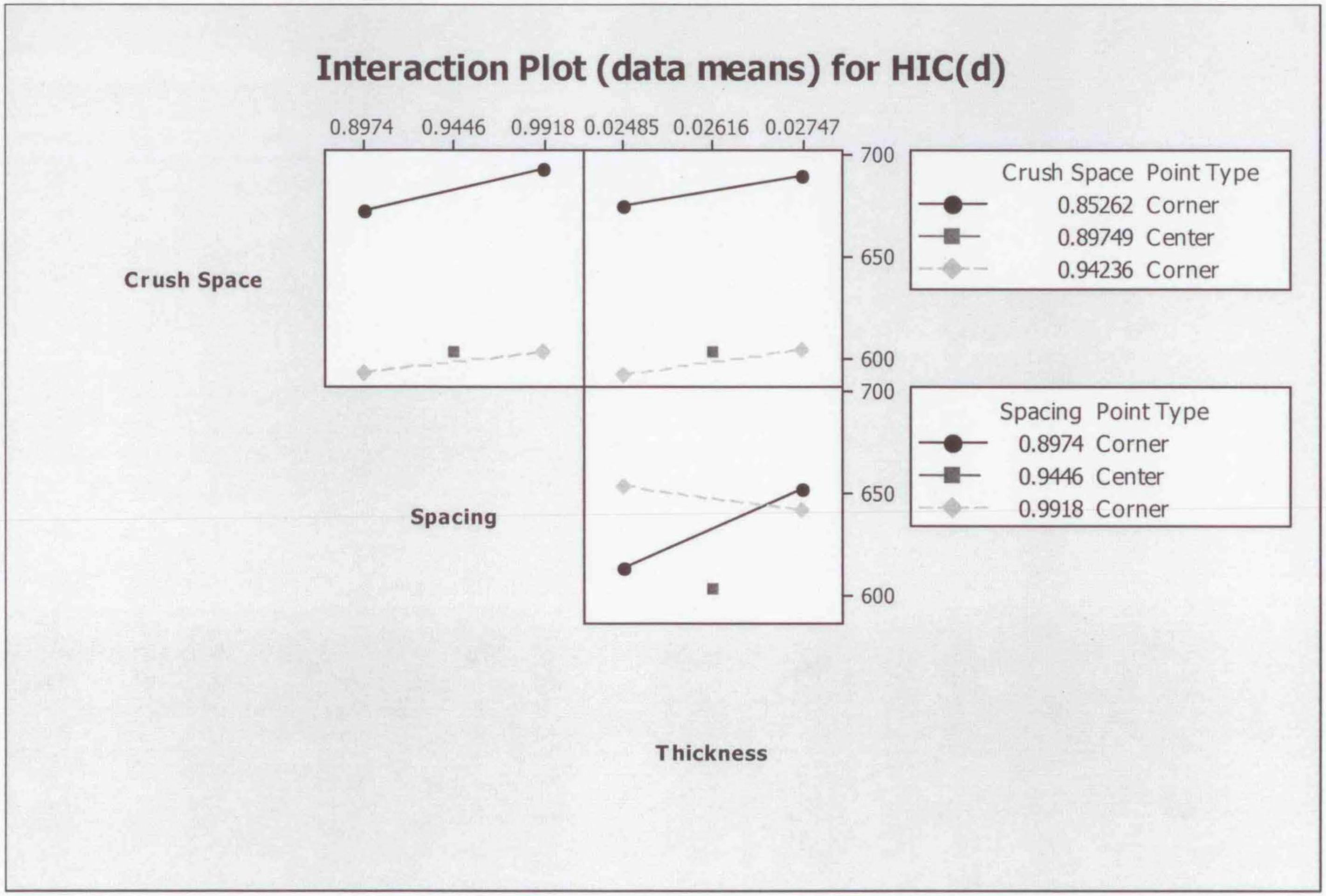
Improved design



- New nominal design settings ± 5%
- Moderate (~ 0.1 inch) increase in nominal crush space yields HIC(d) < 700

Improved design interaction



Response surfaces for the improved design

- Sampled by means of uniform designs
- Developed response surfaces via Kriging
- Factorial simulation results were used to compare fidelity of Kriging response surfaces generated in various ways

Kriging

$$y_{krige} = \sum_{k=1}^{p} \beta_k \, f_k\,(\,\vec{x}\,) + Z\,(\,\vec{x}\,)$$

$$R\,(\,x_i - x_j\,) = \exp[\,-\theta\,(\,x_i - x_j\,)^2\,]$$

Kriging models

- Compared results for surfaces generated with
  - constant
  - first order polynomial
  - quadratic polynomial
- Gaussian correlation function
- Three different sample sizes – 9, 17, and 30

Goodness-of-fit estimates

$$Maximum\ Error \equiv \max \left| y_{krige,i} - y_{factorial,i} \right|$$

$$RMSE \equiv \left[\sum_i \frac{\left(y_{krige,i} - y_{factorial,i} \right)}{n} \right]^{1/2}$$

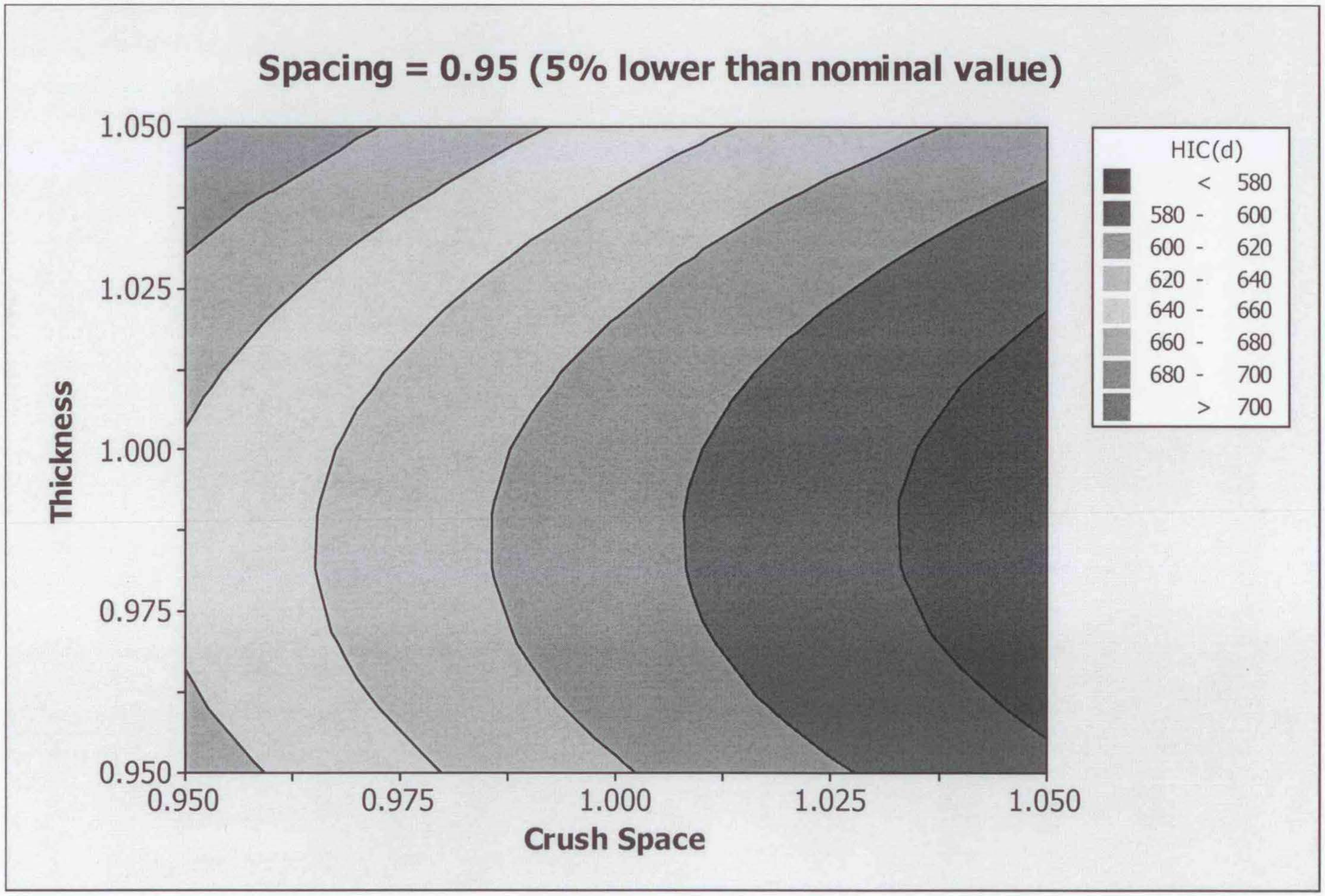
Comparison of maximum error

Sample size	Constant	First Order Polynomial	Quadratic Polynomial
9	42.70	29.52	-
17	125.28	37.44	34.92
30	53.39	30.08	18.66

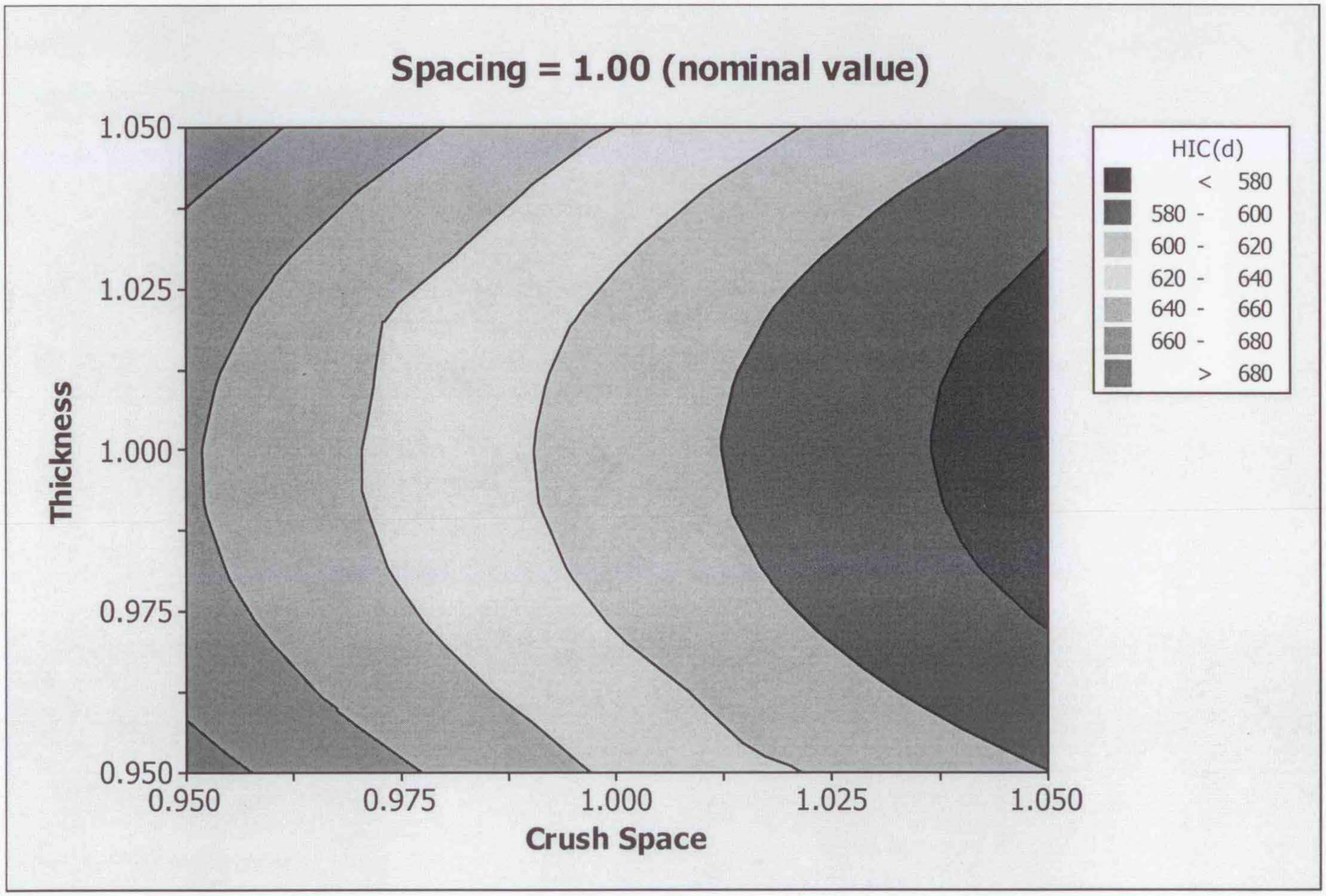
Comparison of root mean square error (RMSE)

Sample size	Constant	First Order Polynomial	Quadratic Polynomial
9	24.36	18.36	-
17	60.50	16.00	19.02
30	23.95	15.04	10.67

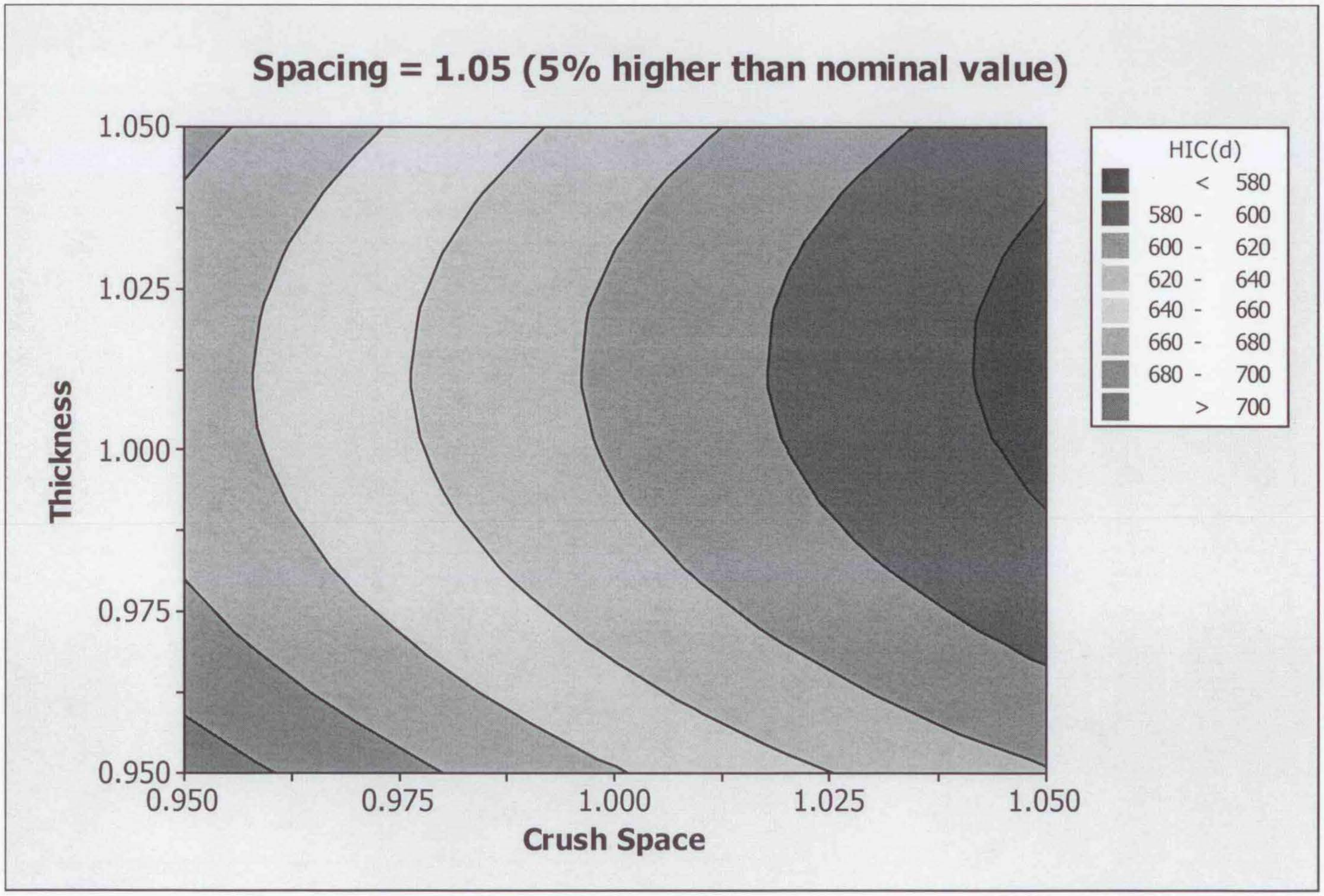
Kriging model contours



Kriging model contours



Kriging model contours



Conclusions

- It's possible to very efficiently optimize an energy absorber design using
  - the LS-DYNA explicit finite element code
  - the successive response surface method algorithm
- Use of classic factorial techniques in combination with Kriging response surfaces can
  - guide improvement of product robustness
  - offer insight into the nature of a product and its performance variability
- An enlightened combination of these techniques enables, if nothing else, valuable and relatively inexpensive insight into the feasibility and behavior of various design concepts.